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ORIGINAL PAPER

Evaluating the effects of environmental regulations on a closed-loop supply chain network: a variational inequality approach

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Abstract Global climate change has encouraged international and regional adoption of pollution taxes and carbon emission reduction policies. Europe has taken the leadership in environmental regulations by introducing the European Union Emissions Trading System (EU-ETS) in 2005 and by promoting a set of policies destined to lower carbon emissions from energy, industrial, and transport sectors. These environmental policies have significantly affected the production choices of these European sectors. Considering this framework, the objective of this paper is to evaluate the effects of the application of environmental policies in a multitiered closed-loop supply chain network where raw material suppliers, manufacturers, consumers, and recovery centers operate. In particular, we assume that manufacturers are subject to the EU-ETS and a carbon tax is imposed on truck transport. In this way, the developed model captures carbon emission regulations, recycling, transportation and technological factors within a unified framework. In particular, it allows for evaluating the impacts of the considered environmental regulations on carbon emissions, product flows, and prices. The proposed model is optimized and solved by using the theory of variational inequalities. Our analysis shows that the combined application of the EU-ETS at the manufacturers' tier and the carbon tax on truck transport implies additional costs for producers that reduce their

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